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Dal Farra

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(54) **TRANSMIT POWER EQUALIZATION IN A RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXER**

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H04Q 11/00 (2006.01)
H04B 10/564 (2013.01)

(52) **U.S. Cl.**
CPC ***H04J 14/0221*** (2013.01); ***H04B 10/564*** (2013.01); ***H04J 14/0212*** (2013.01); ***H04Q 11/0066*** (2013.01)

(58) **Field of Classification Search**
CPC H04J 14/0221; H04J 14/0212; H04B 10/564; H04Q 11/0066
See application file for complete search history.

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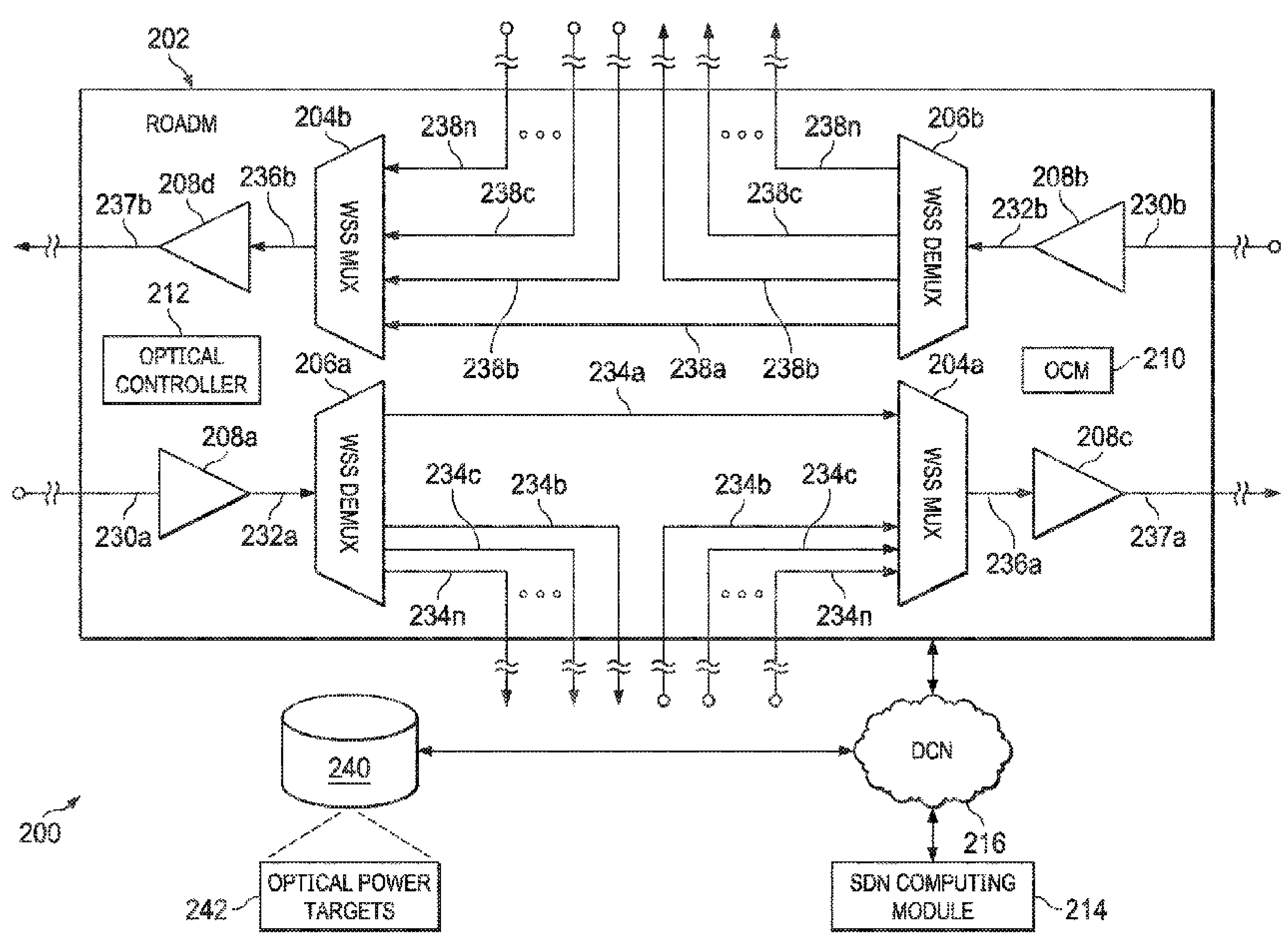
(57) **ABSTRACT**

An optical system including a ROADM including previously in-service channels; a SDN computing module in communication with the ROADM over a DCN, the SDN computing module providing an instruction to place in-service an additional channel at the ROADM; an optical controller included by the ROADM and configured to, in response to the instruction to place in-service the additional channel at the ROADM: obtain optical power targets for each in-service channel including the previously in-service channels and the additional in-service channel; equalize a transmit power for each in-service channel of the ROADM, including: identify the transmit power of each in-service channel; transition each in-service channel to a power mode; adjust the transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified transmit power for the in-service channel; and transition each in-service channel to a steady state mode.

20 Claims, 8 Drawing Sheets



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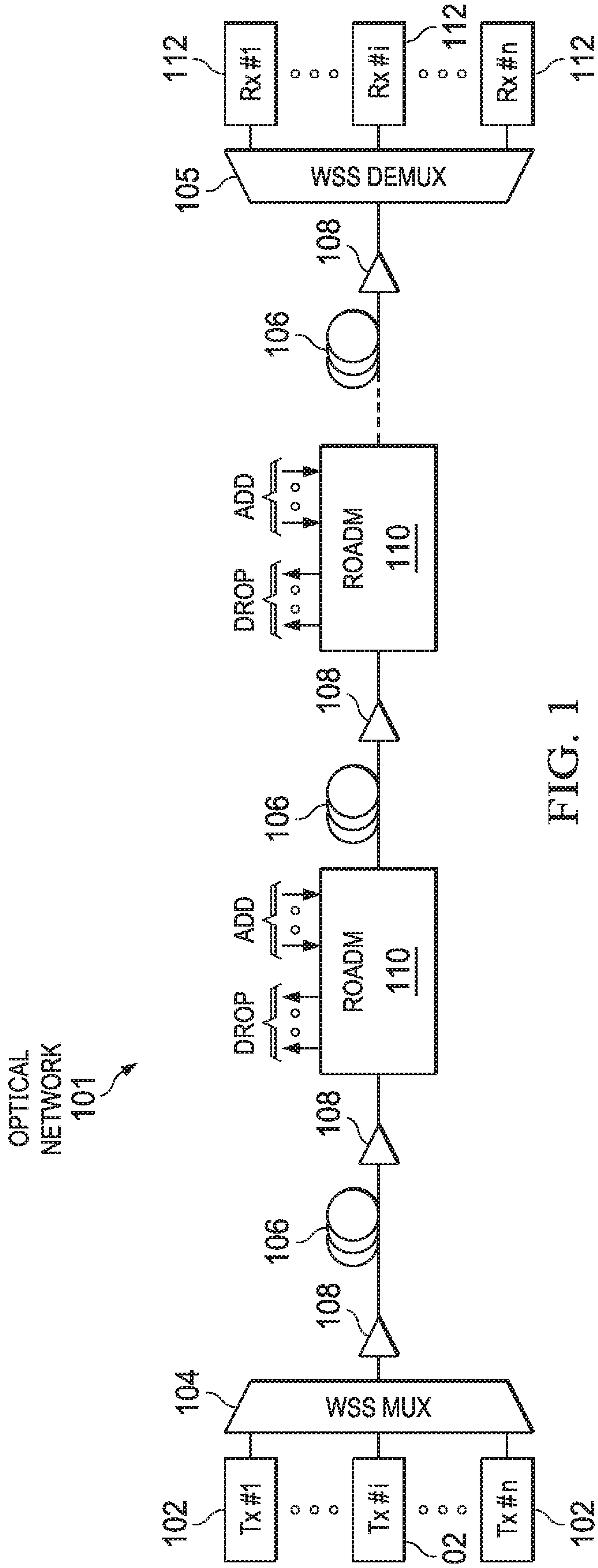
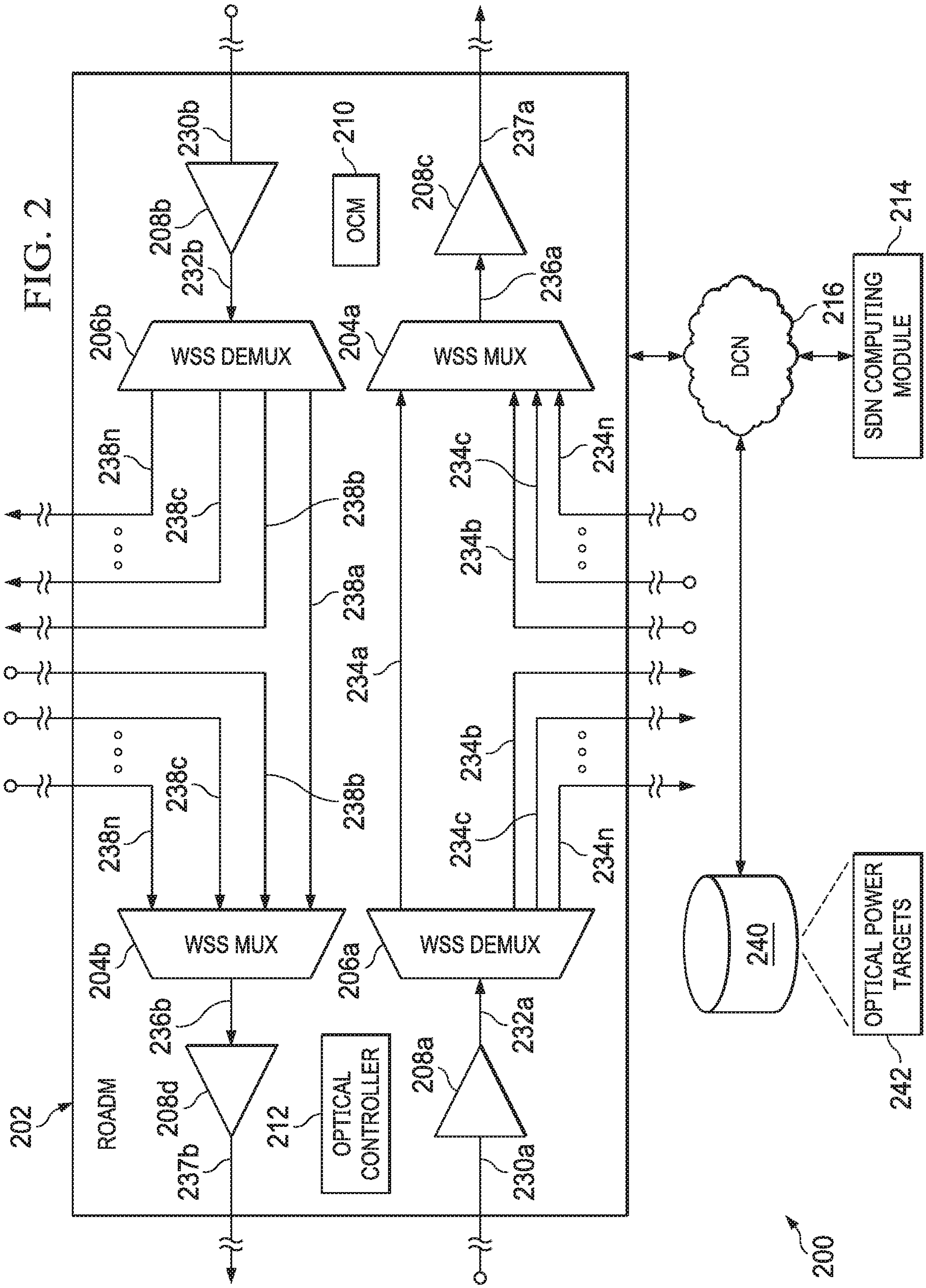

OPTICAL NETWORK 101
102
Tx #1
Tx #i
102
Tx #n
102
WSS MUX
104
108
106
108
DROP
ADD
ROADM
110
106
108
DROP
ADD
ROADM
110
106
108
WSS DEMUX
105
Rx #1
112
Rx #i
112
Rx #n
112

FIG. 1

FIG. 2



202
ROADM
WSS DEMUX
WSS MUX
WSS MUX
WSS DEMUX
OCM
OPTICAL CONTROLLER
DCN
SDN COMPUTING MODULE
240
OPTICAL POWER TARGETS
200
204a
204b
206a
206b
208a
208b
208c
208d
210
212
214
216
230a
230b
232a
232b
234a
234b
234c
234n
236a
236b
237a
237b
238a
238b
238c
238n
242

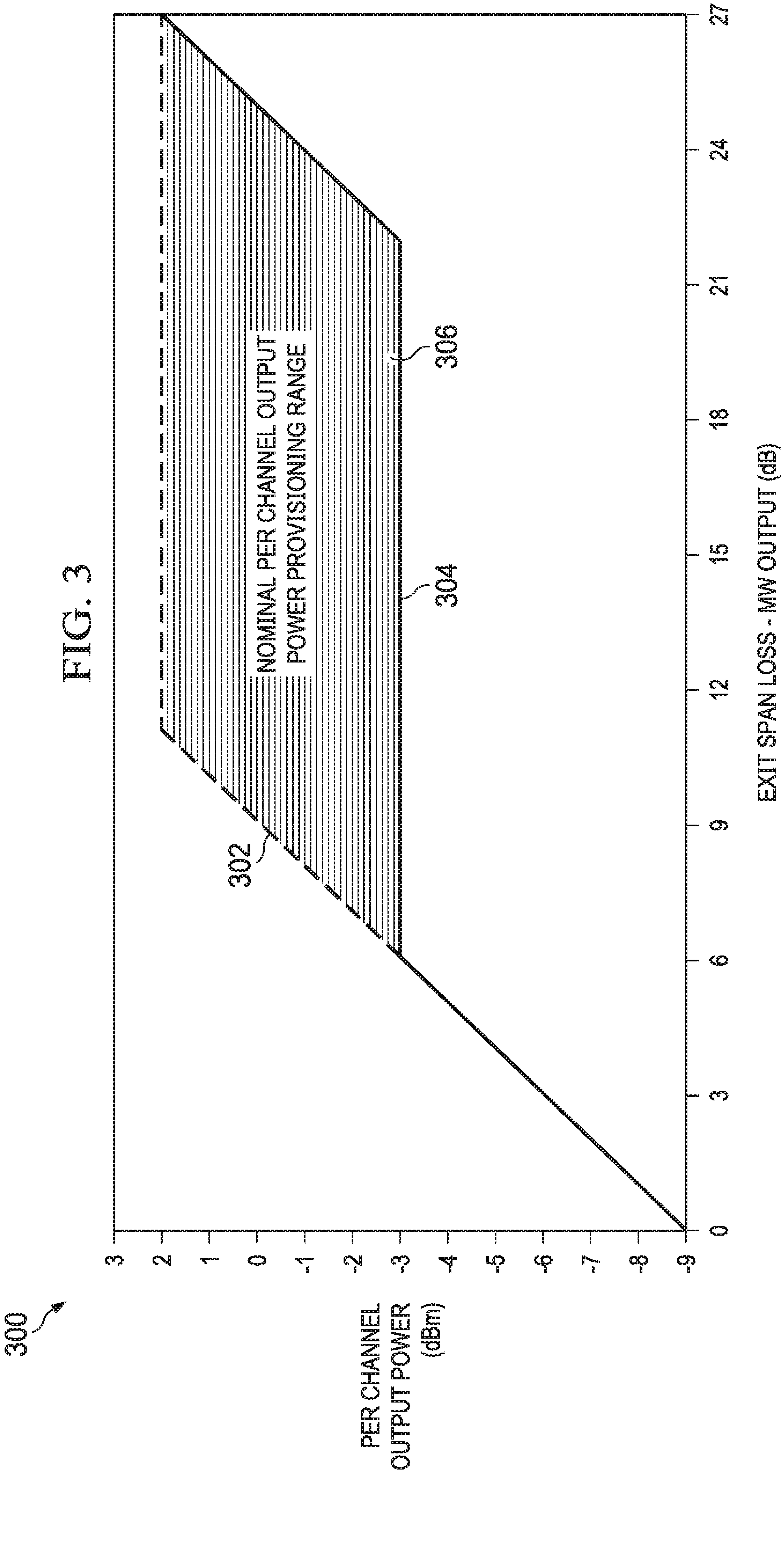

300
PER CHANNEL OUTPUT POWER (dBm)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
EXIT SPAN LOSS - MW OUTPUT (dB)
0
3
6
9
12
15
18
21
24
27
NOMINAL PER CHANNEL OUTPUT POWER PROVISIONING RANGE
302
304
306

FIG. 3

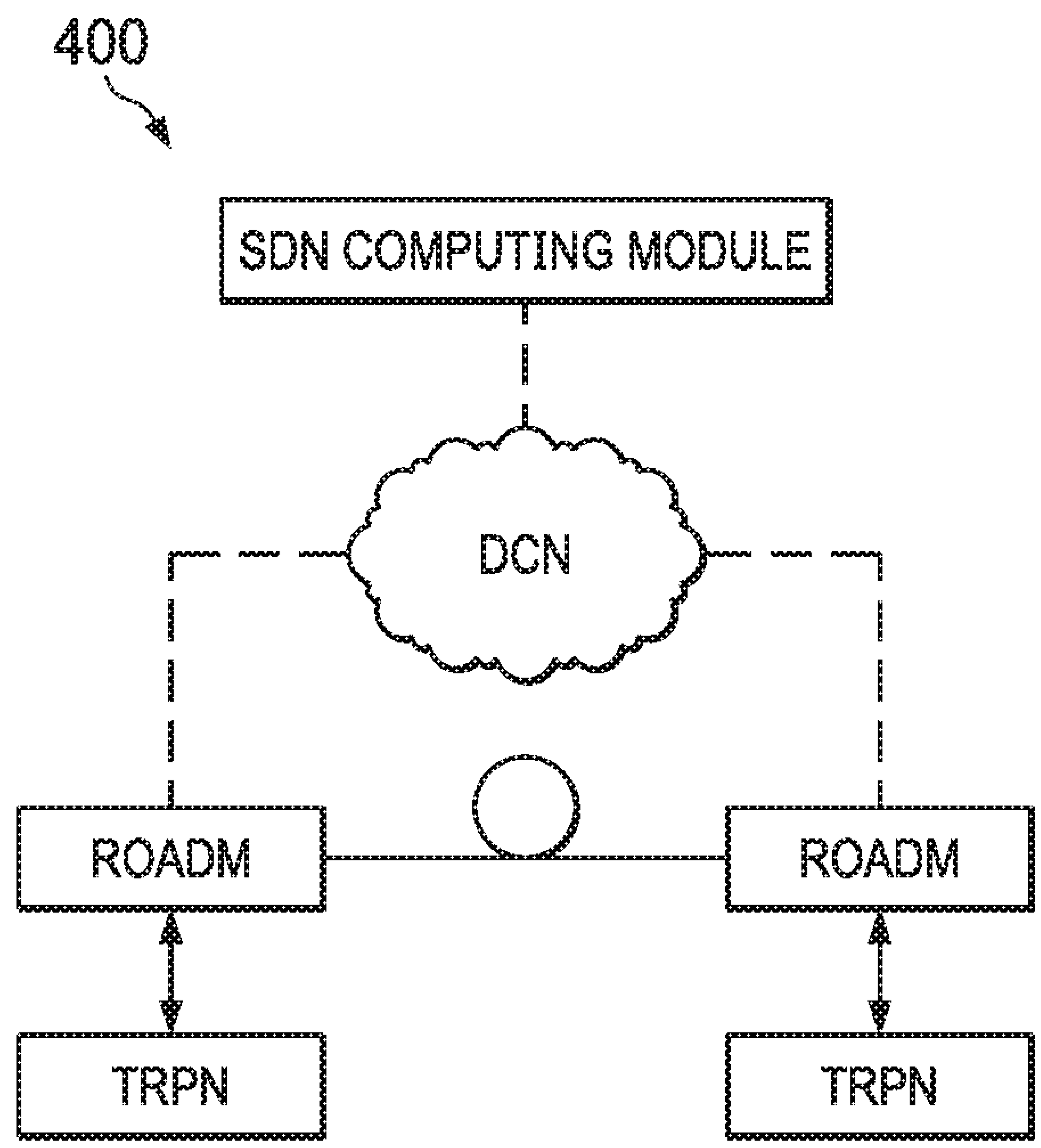

400
SDN COMPUTING MODULE
DCN
ROADM
ROADM
TRPN
TRPN

FIG. 4

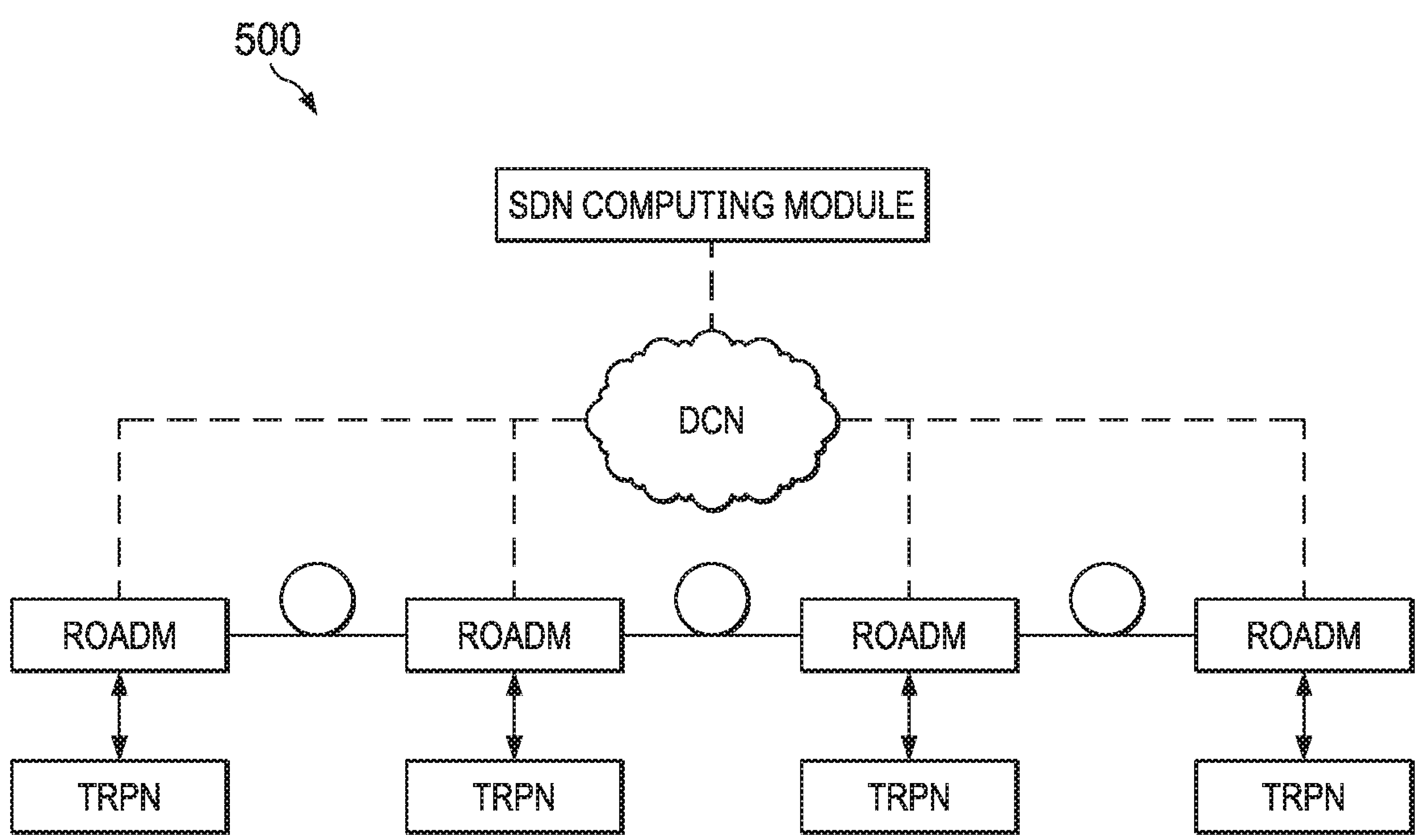

500
SDN COMPUTING MODULE
DCN
ROADM
ROADM
ROADM
ROADM
TRPN
TRPN
TRPN
TRPN

FIG. 5

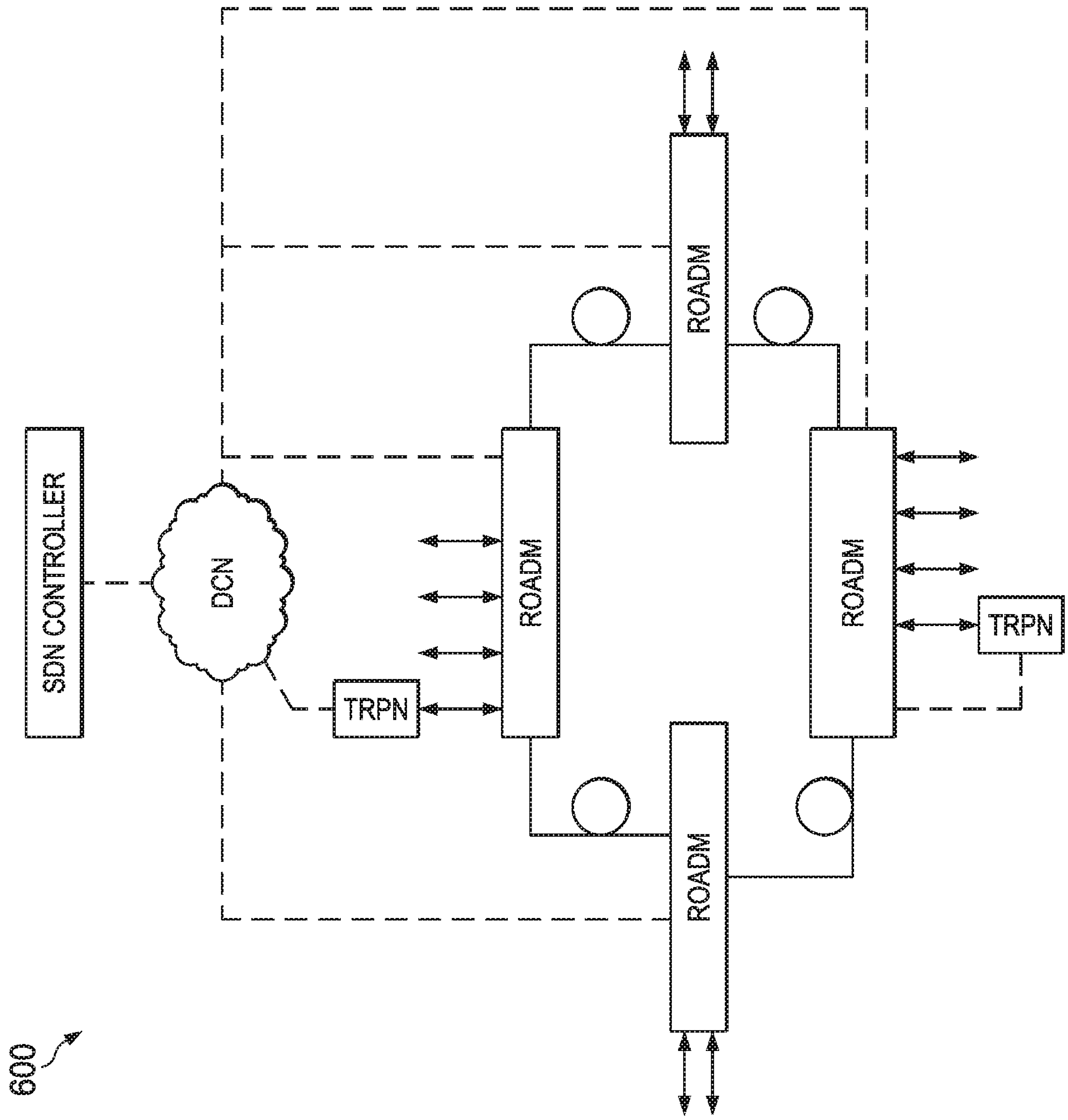


FIG. 6

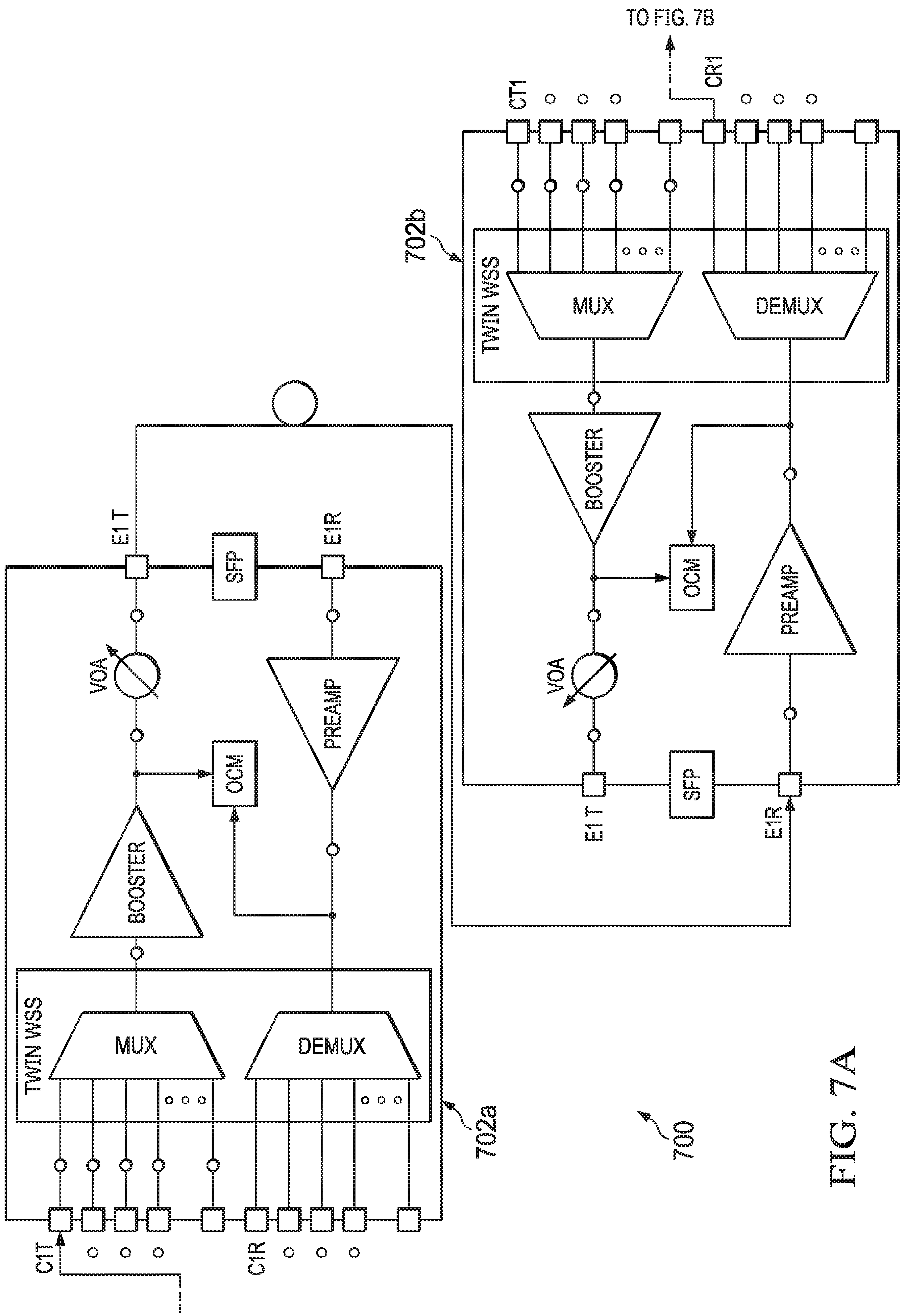

TO FIG. 7B
CT1
CR1
702b
TWIN WSS
MUX
DEMUX
BOOSTER
OCM
PREAMP
VOA
SFP
E1 T
E1R
E1 T
SFP
E1R
VOA
OCM
PREAMP
BOOSTER
TWIN WSS
MUX
DEMUX
702a
C1T
C1R
700

FIG. 7A

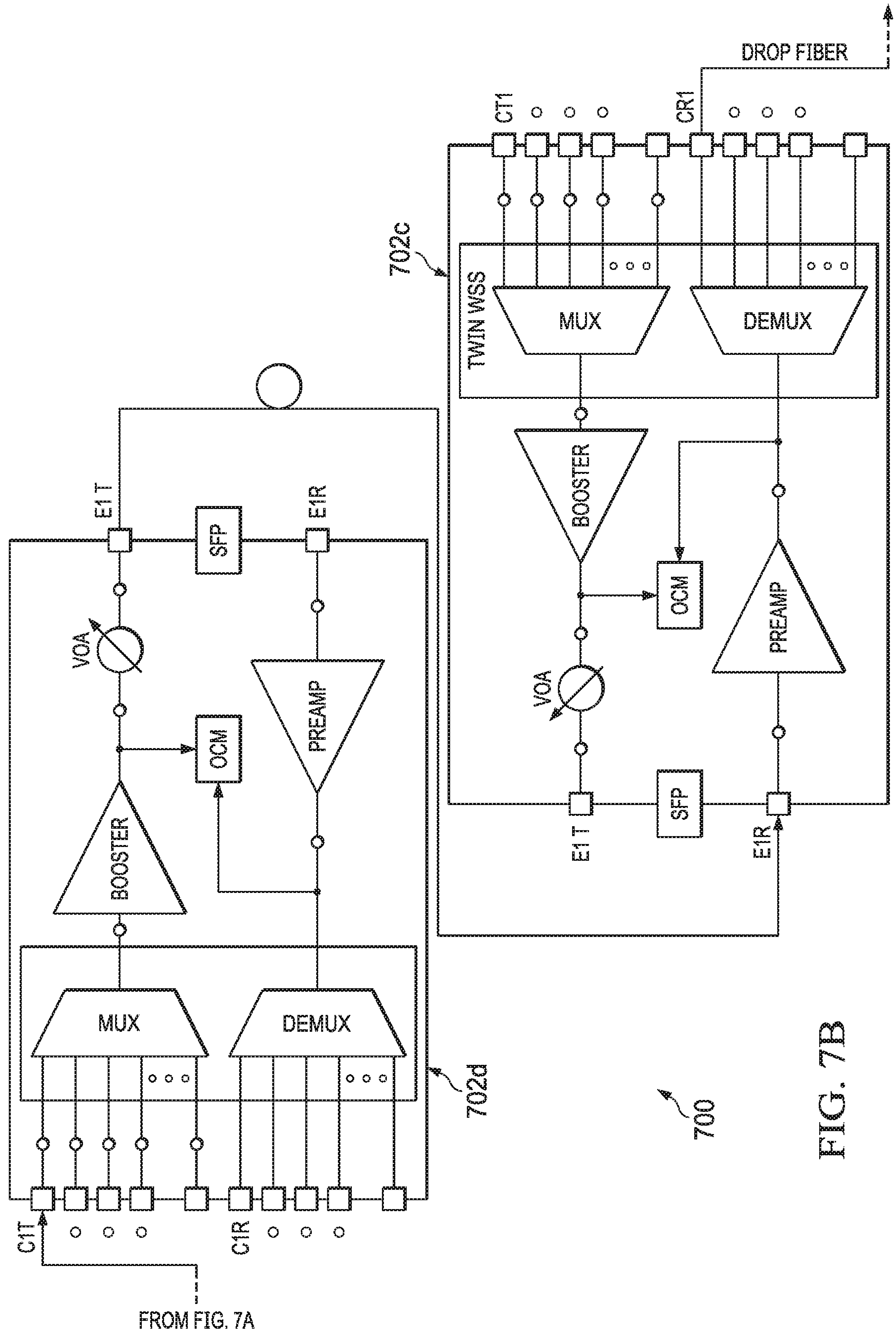

DROP FIBER
CT1
CR1
702c
TWIN WSS
MUX
DEMUX
BOOSTER
OCM
PREAMP
VOA
SFP
E1 T
E1R
702d
C1T
C1R
FROM FIG. 7A
700

FIG. 7B

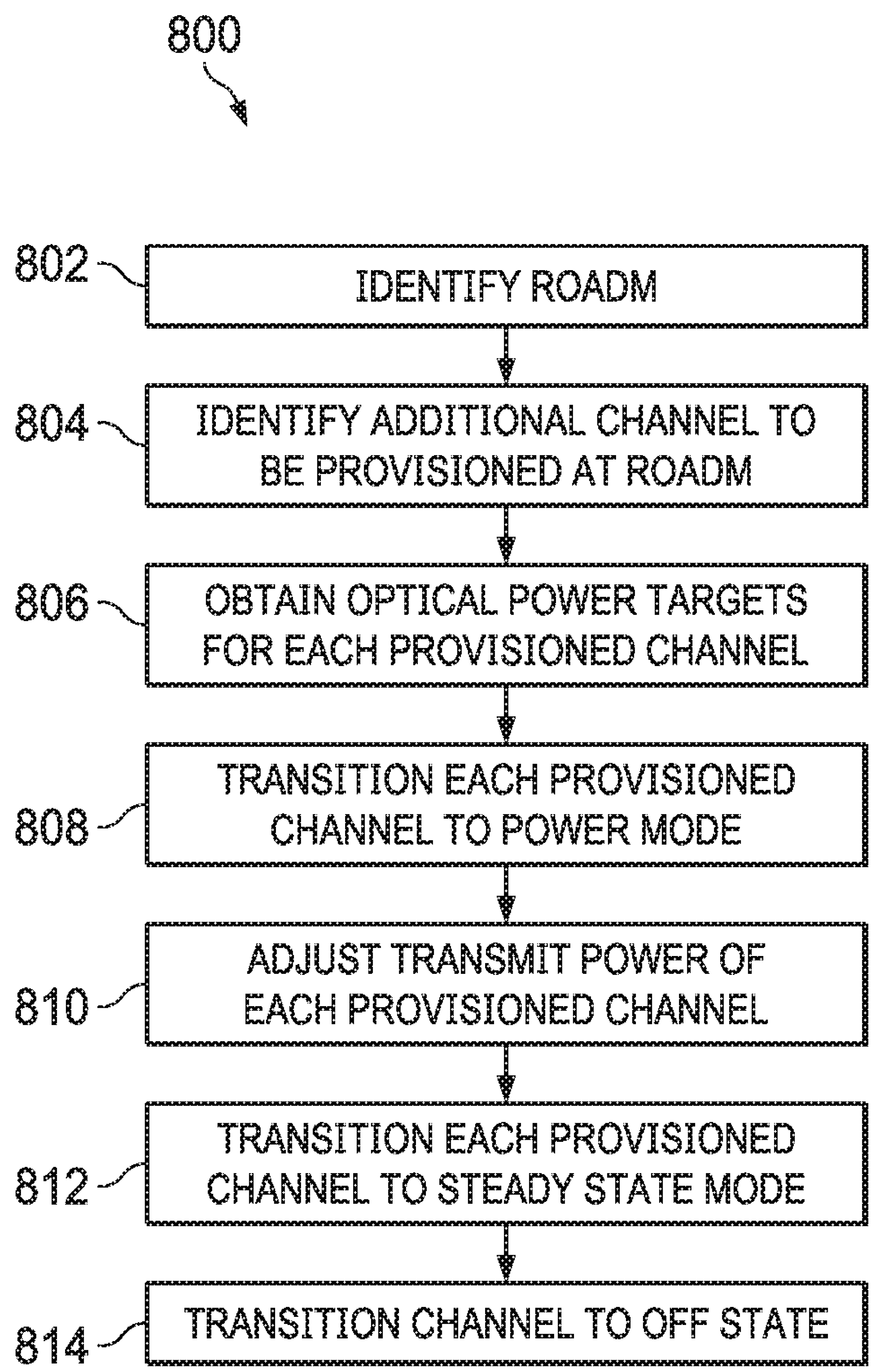

800
802
IDENTIFY ROADM
804
IDENTIFY ADDITIONAL CHANNEL TO BE PROVISIONED AT ROADM
806
OBTAIN OPTICAL POWER TARGETS FOR EACH PROVISIONED CHANNEL
808
TRANSITION EACH PROVISIONED CHANNEL TO POWER MODE
810
ADJUST TRANSMIT POWER OF EACH PROVISIONED CHANNEL
812
TRANSITION EACH PROVISIONED CHANNEL TO STEADY STATE MODE
814
TRANSITION CHANNEL TO OFF STATE

FIG. 8

TRANSMIT POWER EQUALIZATION IN A RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXER

BACKGROUND

Field of the Disclosure

The present disclosure relates generally to optical communication networks and, more particularly, an optical system that facilitates transmit power equalization in a reconfigurable optical add-drop multiplexer (ROADM).

Description of the Related Art

Telecommunication, cable television and data communication systems use optical networks to rapidly convey large amounts of information between remote points. In an optical network, information is conveyed in the form of optical signals through optical fibers. Optical fibers may comprise thin strands of glass capable of communicating the signals over long distances. Optical networks often employ modulation schemes to convey information in the optical signals over the optical fibers. Such modulation schemes may include phase-shift keying (PSK), frequency-shift keying (FSK), amplitude-shift keying (ASK), and quadrature amplitude modulation (QAM).

Optical networks may also include various optical elements, such as amplifiers, dispersion compensators, multiplexer/demultiplexer filters, wavelength selective switches (WSS), optical switches, splitters, couplers, etc. to perform various operations within the network. In particular, optical networks may include reconfigurable optical add-drop multiplexers (ROADMs) that enable routing of optical signals and individual wavelengths to different destinations.

ROADMs, when implemented in an open (non-proprietary) optical network, may not be allowed to communicate optical control information between nodes in the network. As a result, they do not compensate for changes in optical powers of existing wavelength services when new services are turned up or turned down, setting only the newly provisioned wavelength services to target. This can lead to regenerating the signal more frequently, and additional costs on the optical network.

SUMMARY

Innovative aspects of the subject matter described in this specification may be embodied in a method for identifying a reconfigurable optical add-drop multiplexer (ROADM), the ROADM including a plurality of previously in-service channels; identifying, by an optical controller, an additional channel that is to be placed in-service at the ROADM; in response to identifying that the additional channel is to be placed in-service at the ROADM: obtaining, by the optical controller, optical power targets for each in-service channel including the plurality of previously in-service channels and the additional in-service channel; equalizing, by the optical controller, a transmit power for each in-service channel of the ROADM, including: identifying the transmit power of each in-service channel; transitioning, at the ROADM, each in-service channel to a power mode; after transitioning each in-service channel to the power mode, adjusting, at the ROADM, the transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified transmit power for the in-service channel; and after adjusting the transmit power of each in-service channel, transitioning, at the ROADM, each previously in-service channel to a steady state mode independent of instruction from a software-defined networking (SDN) computing module.

Other embodiments of these aspects include corresponding systems and apparatus.

These and other embodiments may each optionally include one or more of the following features. For instance, after equalizing the transmit power for each in-service channel of the ROADM, at a first time, equalizing, by the optical controller and at a second time after the first time, the transmit power for each in-service channel, including: identifying an updated transmit power of each in-service channel; and adjusting, at the ROADM, the updated transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified updated transmit power for the in-service channel. Adjusting a first in-service channel by increasing the transmit power of the first in-service channel; and adjusting a second in-service channel by decreasing a transmit power of the second in-service channel. Receiving, for each in-service channel, the optical power targets over a network from the SDN computing module. The optical controller equalizes the transmit power for each previously in-service channel only in response to instructions from the SDN computing module to transition the additional channel to the power mode. The transmit power is equalized, for each previously in-service channel, less than or equal to a threshold number of times. In response to identifying that the additional channel is to be placed in-service, the transmit power of each in-service channel is adjusted initially at a first multiplexer connected to an add transponder and proceed in sequence downstream through each node serially including a far end drop node.

Innovative aspects of the subject matter described in this specification may be embodied in a method for identifying a reconfigurable optical add-drop multiplexer (ROADM), the ROADM including a plurality of previously in-service channels; identifying, by an optical controller, that a previously in-service channel is to be placed out of service at the ROADM; in response to identifying that the previously in-service channel is to be placed out of service at the ROADM: obtaining, by the optical controller, optical power targets for each in-service channel; equalizing, by the optical controller, a transmit power for each in-service channel of the ROADM, including: identifying the transmit power of each in-service channel; transitioning, at the ROADM, each in-service channel to a power mode; after transitioning each in-service channel to the power mode, adjusting, at the ROADM, the transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified transmit power for the in-service channel; and after adjusting the transmit power of each in-service channel, transitioning, at the ROADM, each remaining in-service channel to a steady state mode independent of instructions from a software-defined networking (SDN) computing module.

Other embodiments of these aspects include corresponding systems and apparatus.

These and other embodiments may each optionally include one or more of the following features. For instance, after equalizing the transmit power for each in-service channel of the ROADM, at a first time, equalizing, by the optical controller and at a second time after the first time, the transmit power for each in-service channel, including: identifying an updated transmit power of each in-service channel; and adjusting, at the ROADM, the updated transmit

power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified updated transmit power for the in-service channel. Adjusting a first in-service channel by increasing the transmit power of the first in-service channel; and adjusting a second in-service channel by decreasing a transmit power of the second in-service channel. Receiving, for each in-service channel, the optical power targets over a network from the SDN computing module. The optical controller equalizes the transmit power for each in-service channel only in response to instructions from the SDN computing module to transition the additional channel to the power mode. The transmit power is equalized, for each previously in-service channel, less than or equal to a threshold number of times. In response to identifying that the previously in-service channel is to be placed out of service, the transmit power of each in-service channel is adjusted initially at a first multiplexer connected to a drop transponder and proceed in sequence upstream through each node serially including an add node.

Innovative aspects of the subject matter described in this specification may be embodied in a system including a reconfigurable optical add-drop multiplexer (ROADM), the ROADM including a plurality of previously in-service channels; a software-defined networking (SDN) computing module in communication with the ROADM over a dynamic circuit network (DCN), the SDN computing module providing an instruction to place in-service an additional channel at the ROADM; an optical controller included by the ROADM and configured to, in response to the instruction to place in-service the additional channel at the ROADM: obtain optical power targets for each in-service channel including the plurality of previously in-service channels and the additional in-service channel; equalize a transmit power for each in-service channel of the ROADM, including: identify the transmit power of each in-service channel; transition, at the ROADM, each in-service channel to a power mode; after transitioning each in-service channel to the power mode, adjust, at the ROADM, the transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified transmit power for the in-service channel; and after adjusting the transmit power of each in-service channel, transition, at the ROADM, each previously in-service channel to a steady state mode independent of instruction from a software-defined networking (SDN) computing module.

Other embodiments of these aspects include corresponding methods and apparatus.

These and other embodiments may each optionally include one or more of the following features. For instance, adjusting a first in-service channel by increasing the transmit power of the first in-service channel; and adjusting a second in-service channel by decreasing a transmit power of the second in-service channel. Receiving, for each in-service channel, the optical power targets over a network from the SDN computing module. The transmit power is equalized, for each previously in-service channel, less than or equal to a threshold number of times. In response to identifying that the additional channel is to be placed in-service, the transmit power of each in-service channel is adjusted initially at a first multiplexer connected to an add transponder and proceed in sequence downstream through each node serially including a far end drop node. The optical controller further configured to: after equalizing the transmit power for each in-service channel of the ROADM, at a first time, equalizing, by the optical controller and at a second time after the first time, the transmit power for each in-service channel, including: identifying an updated transmit power of each in-service channel; and adjusting, at the ROADM, the updated transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified updated transmit power for the in-service channel.

Particular implementations of the subject matter described in this specification can be implemented so as to realize one or more of the following advantages through a reduction in channel imbalance caused by system gain ripple or non-linearity (for example stimulated Raman scattering (SRS)): improvements to network end to end optical reach, reduction of signal regeneration, and reduced risk of ring lasing.

The details of one or more embodiments of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other potential features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and its features and advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a block diagram of selected elements of an embodiment of an optical network.

FIG. **2** is a block diagram for an optical environment.

FIG. **3** illustrates a graph displaying a nominal per channel power provisioning range for in-service channels.

FIG. **4** illustrates a point-to-point optical network.

FIG. **5** illustrates a linear optical network.

FIG. **6** illustrates a ring optical network.

FIGS. **7**A, **7**B illustrate an optical environment including three optical nodes.

FIG. **8** illustrates a flowchart for transmit power equalization.

DESCRIPTION OF PARTICULAR EMBODIMENT(S)

This document describes a method and a system for re-equalizing in-service wavelengths in an optical environment when a new service is turned up or an existing service is turned down. Specifically, an optical power controller can be executed independently by ROADM nodes of the optical environment during service turn up and/or service turn down. The optical controller can facilitate equalizing all in-service wavelengths to a target optical power based on optical power readings provided by an optical channel monitor and optical targets when any one service is turned up or turned down.

In the following description, details are set forth by way of example to facilitate discussion of the disclosed subject matter. It should be apparent to a person of ordinary skill in the field, however, that the disclosed embodiments are exemplary and not exhaustive of all possible embodiments.

Throughout this disclosure, a hyphenated form of a reference numeral refers to a specific instance of an element and the un-hyphenated form of the reference numeral refers to the element generically or collectively. Thus, as an example (not shown in the drawings), device "12-1" refers to an instance of a device class, which may be referred to collectively as devices "12" and any one of which may be referred to generically as a device "12". In the figures and the description, like numerals are intended to represent like elements.

As noted above, ROADMs are deployed in many applications in optical networks. Typical ROADMs are designed to accommodate any number of degrees, each of which may support up to any number of optical channels or wavelengths (e.g., 128 or more) in particular implementations. In describing a ROADM generally, a 'degree' is a term used to describe a switched optical path to or from the ROADM, which may be a bidirectional optical path or a pair of optical fibers in some instances.

Referring now to the drawings, FIG. **1** illustrates an example embodiment of optical network **101**, which may represent a portion of an optical communication system. Optical network **101** may include one or more optical fibers **106** to transport one or more optical signals communicated by components of optical network **101**. The network elements of optical network **101**, coupled together by fibers **106**, may comprise one or more transmitters **102**, one or more optical amplifiers **108**, one or more reconfigurable optical add/drop multiplexers (ROADM) **110**, one or more multiplexers (MUX) **104**, one or more demultiplexers (DEMUX) **105**, and one or more receivers **112**. The optical network **101** can represent a portion of a bidirectional optical network, e.g., a unidirectional portion of a bidirectional optical network.

Optical network **101** may comprise a point-to-point optical network with terminal nodes, a ring optical network, a mesh optical network, or any other suitable optical network or combination of optical networks. Optical network **101** may be used in a short-haul metropolitan network, a long-haul inter-city network, or any other suitable network or combination of networks. The capacity of optical network **101** may include any data rate, for example, 100 Gbit/s, 400 Gbit/s, or 1 Tbit/s. Optical fibers **106** may comprise a suitable type of fiber selected from a variety of different fibers for optical transmission. Optical fibers **106** may include any suitable type of fiber, such as a Single-Mode Fiber (SMF), Enhanced Large Effective Area Fiber (E-LEAF), or TrueWave® Reduced Slope (TW-RS) fiber.

Optical network **101** may include devices to transmit optical signals over optical fibers **106**. Information may be transmitted and received through optical network **101** by modulation of one or more wavelengths of light to encode the information on the wavelength. In optical networking, a wavelength of light may also be referred to as a channel that is included in an optical signal (also referred to herein as a "wavelength channel"). Each channel may carry a certain amount of information through optical network **101**.

To increase the information capacity and transport capabilities of optical network **101**, multiple signals transmitted at multiple optical channels may be combined into a single wideband optical connection. The process of communicating information at multiple channels is referred to in optics as wavelength division multiplexing (WDM).

Optical network **101** may include one or more optical transmitters (Tx) **102** to transmit optical signals through optical network **101** in specific wavelengths or channels. Transmitters **102** may comprise a system, apparatus or device to convert an electrical signal into an optical signal and transmit the optical signal. For example, transmitters **102** may each comprise a laser and a modulator to receive electrical signals (or optical signals) and modulate the information contained in the electrical signals onto a beam of light produced by the laser at a particular wavelength, and transmit the beam for carrying the signal throughout optical network **101**.

MUX **104** may be coupled to transmitters **102** and may be a system, apparatus or device to combine the signals transmitted by transmitters **102**, e.g., at respective individual wavelengths, into a WDM connection.

Optical amplifiers **108** may amplify the multi-channeled connections within optical network **101**. Optical amplifiers **108** may be positioned before or after certain lengths of fiber **106**. Optical amplifiers **108** may comprise a system, apparatus, or device to amplify optical signals.

ROADMs **110** may be coupled to optical network **101** via fibers **106**. ROADMs **110** comprise an add/drop module, which may include a system, apparatus or device to add and drop optical signals (for example at individual wavelengths) or to passthrough wavelengths to other degrees from fibers **106**. After passing through a ROADM **110**, optical signals may travel along fibers **106** directly to a destination, or the signals may be passed through one or more additional ROADMs **110** and optical amplifiers **108** before reaching a destination.

In certain embodiments of optical network **101**, ROADM **110** is capable of adding or dropping individual or multiple wavelengths of a WDM connection. The individual or multiple wavelengths may be added or dropped in the optical domain, for example, using a wavelength selective switch (WSS) that may be included in a ROADM. ROADMs are considered 'colorless' when the ROADM is able to add/drop any arbitrary wavelength. ROADMs are considered 'directionless' when the ROADM is able to add/drop any viable wavelength regardless of the direction of propagation. ROADMs are considered 'contentionless' when the ROADM is able to switch to avoid wavelength contention (already occupied wavelength) on any port. As shown ROADM **110** may represent an implementation of a route and select ROADM, as disclosed herein.

As shown in FIG. **1**, optical network **101** may also include DEMUX **105** at one or more destinations of network **101**. DEMUX **105** may comprise a system apparatus or device that acts as a demultiplexer by splitting a single composite WDM connection into individual channels at respective wavelengths or into groups of channels to a port. For example, optical network **101** may transmit and carry a 128 channel DWDM connection. DEMUX **105** may divide the single, 128 channel DWDM connection into multiple signals with arbitrary wavelength assignment.

In FIG. **1**, optical network **101** may also include receivers **112** coupled to ROADM **105**. Each receiver **112** may receive optical signals transmitted at a particular wavelength or channel, and may process the optical signals to obtain (e.g., demodulate) the information (i.e., data) that the optical signals contain. Accordingly, network **101** may include up to one receiver **112** for every channel of the network. Transmitters **102** may transmit the optical signal locally or to other degrees.

Optical networks, such as optical network **101** in FIG. **1**, may employ modulation techniques to convey information in the optical signals over the optical fibers.

In an optical network, such as optical network **101** in FIG. **1**, it is typical to refer to a management plane and a transport plane (sometimes called the physical layer). A central management host (not shown) may reside in the management plane and may configure and supervise the components of the control plane. The management plane includes ultimate control over all transport plane and control plane entities (e.g., network elements). As an example, the management plane may consist of a central processing center (e.g., the central management host), including one or more processing resources, data storage components, etc. The management plane may be in electrical communication with the elements of the control plane and may also be in electrical communication with one or more network elements of the transport plane. The management plane may perform management functions for an overall system and provide coordination between network elements, the control plane, and the transport plane. As examples, the management plane may include an element management system (EMS) which handles one or more network elements from the perspective of the elements, a network management system (NMS) which handles many devices from the perspective of the network, and an operational support system (OSS) which handles network-wide operations.

Modifications, additions or omissions may be made to optical network **101** without departing from the scope of the disclosure. For example, optical network **101** may include more or fewer elements than those depicted in FIG. **1**. Also, as mentioned above, although depicted as a point-to-point network, optical network **101** may comprise any suitable network topology for transmitting optical signals such as a ring, a mesh, and a hierarchical network topology.

FIG. **2** illustrates an optical environment **200**. The optical environment **200** can include a reconfigurable optical add-drop multiplexer (ROADM) **202**. The ROADM **202** can include multiplexers **204***a*, **204***b* (collectively referred to as multiplexers **204**), demultiplexers **206***a*, **206***b* (collectively referred to as demultiplexers **206**), optical amplifiers **208***a*, **208***b*, **208***c*, **208***d* (collectively referred to as optical amplifiers **208**), an optical channel monitor (OCM) **210**, and an optical controller **212**. In some examples, the optical environment **200** can incorporate one or more elements of the optical network **101**.

The optical environment **200** can further include a software-defined networking (SDN) computing module **214** in communication with the ROADM **202** over a dynamic circuit network (DCN) **216**. In some examples, the multiplexers **204** and the demultiplexers **206** can function as an optical module, and include one or more processors. The multiplexers **204** can include wavelength selective switching (WSS) multiplexers, and the demultiplexers **206** can include WSS demultiplexers. In some examples, the optical environment **200** can include two or more ROADMs, described further herein.

The optical controller **212** can be in communication with the SDN computing module **214**, and/or the DCN **216**. In some examples, the optical controller **212** is in communication with the multiplexers **204** and the demultiplexers **206**. The optical controller **212** can include one or more processing modules to facilitate equalizing transmit powers at the ROADM **202**, described further herein. The optical environment **200** can further include a database **240** that can store data indicating optical power targets **242**.

Passthrough connection **234***a* can extend between the demultiplexer **206***a* and the multiplexer **204***a*, and carry one or more channels with respective wavelengths (or colors, or services) being transmitted on the respective channels between the demultiplexer **206***a* and the multiplexer **204***a*. Similarly, passthrough connection **238***a* can extend between the demultiplexer **206***b* and the multiplexer **204***b*, and carry multiple channels with respective wavelengths (or colors, or services) being transmitted on the respective channels between the demultiplexer **206***b* and the multiplexer **204***b*.

Optical connections **234***b*, **234***c*, . . . **234***n* (collectively referred to as optical connections **234**) and optical connections **238***b*, **238***c*, . . . , **238***n* (collectively referred to as optical connections **238**) can be local add/drops or connections to other degrees and carry multiple channels with respective wavelengths being transmitted on the respective channels. For example, optical connections **234**, **238** can be in communication with further optical components, e.g., passthroughs to other degrees or add/drop channels. For example, one or more of the optical connections **234**, **238** can be in communication with a further local transponder, an external multiplexer or demultiplexer, and/or to a separate multiplexer or demultiplexer that supports another degree (e.g., to create a mesh network). Each of the optical connections **234**, **238** can carry multiple channels with respective wavelengths.

The optical amplifier **208***a* can receive input signals **230***a*. The input signals **230***a* can include a set of wavelengths (or colors, or services). The optical amplifier **208***a* can amplify the signals **230***a* to produce signals **232***a*. The demultiplexer **206***a* can receive the signals **232***a*. The demultiplexer **206***a* can split (or partition) the signals **232***a* into multiple sets of wavelengths that are transmitted over respective passthrough connection **234***a* and/or optical connections **234***b*, **234***c*, . . . , **234***n*. In some examples, a subset of the channels of the passthrough connection **234***a* and the optical connections **234***b*, **234***c*, . . . , **234***n* are placed in-service to transmit respective wavelengths. For example, the passthrough connection **234***a* can include 96 channels; however, only 90 channels of the 96 channels of the passthrough connection **234***a* are in-service—i.e., the demultiplexer **206***a* routes 90 wavelengths that are transmitted over the in-service channels. The multiplexer **204***a* can receive the wavelengths of the channels over the passthrough connection **234***a* and the optical connections **234***b*, **234***c*, . . . , **234***n* and combine the wavelengths to produce signals **236***a*. In some examples, the multiplexer **204***a* combines the signals from the passthrough connection **234***a* with a signal from one or more of the optical connections **234***b*, **234***c*, . . . , **234***n*. The optical amplifier **208***c* can receive the signals **236***a* and amplify the signals to produce signals **237***a*.

Similarly, the optical amplifier **208***b* can receive input signals **230***b*. The input signals **230***b* can include a set of wavelengths (or colors, or services). The optical amplifier **208***b* can amplify the signals **230***b* to produce signals **232***b*. The demultiplexer **206***b* can receive the signals **232***b*. The demultiplexer **206***b* can split (or partition) the signals **232***b* into multiple sets of wavelengths that are transmitted over respective channels of the passthrough connection **238***a* and/or the optical connections **238***b*, **238***c*, . . . , **238***n*. In some examples, a subset of the channels of the passthrough connection **238***a* and/or the optical connections **238***b*, **238***c*, . . . , **238***n* transmit respective wavelengths. For example, the passthrough connection **238***a* can include 96 channels; however, only 90 channels of the 96 channels of the passthrough connection **238***a* are in-service—i.e., the demultiplexer **206***b* routes 90 wavelengths that are transmitted over the in-service channels. The multiplexer **204***b* can receive the wavelengths of the channels over the passthrough connection **238***a* and/or the optical connections **238***b*, **238***c*, . . . , **238***n* and combine the wavelengths to produce signals **236***b*. In some examples, the multiplexer **204***b* combines the signals from the passthrough connection **238***a* with a signal from one or more of the optical connections **238***b*, **238***c*, . . . , **238***n*. The optical amplifier **208***d* can receive the signals **236***b* and amplify the signals to produce signals **237***b*.

The ROADM **202** can be a two-degree ROADM; however, the ROADM **202** can be any degree ROADM depending on the application desired.

The optical channel monitor (OCM) **210** can monitor an optical transmit power (or optical power, or transmit power) of any combination of the in-service channels of the passthrough connections **234***a*, **238***b*; the optical connections **234***b*, **234***c*, . . . **234***n*, the optical connections **238***b*, **238***c*, . . . , **238***n*, the signals **230***a*, **230***b*, **237***a*, **237***b*, and/or the signals **232***a*, **232***b*, **236***a*, **236***b*. For simplicity of illustration, connections between the optical channel monitor **210** and the respective channels and signals is not shown.

The SDN computing module **214** can manage the ROADM **202**, including placing in-service of new channels (turning up) at the ROADM **202**, placing out of service channels (turning down) at the ROADM **202**, restart/power cycle of the ROADM **202**, span loss measurement and adjustment at the ROADM **202**, and fiber cut recovery, described further herein. The SDN computing module **214** can further transition the signals at the ROADM **202** to different operating modes including constant power (power mode), steady state ("gainLoss" mode), and off-mode, described further herein.

In some implementations, the optical controller **212** can identify an additional channel that is to be placed in-service at the ROADM **202**. For example, the SDN computing module **214** can provide such instructions to the ROADM **202** over the DCN **216**, e.g., that an additional channel is to be in-service at the ROADM **202**. That is, an additional channel is to be added at the multiplexer **204***a*.

The optical controller **212**, in response to identifying an additional channel is to be placed in-service at the ROADM **202**, can obtain the optical power targets **242** (or data indicating the optical power targets **242**) for each in-service channel. For example, the optical controller **212** can obtain the optical power targets **242** for each in-service channel of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n*. Specifically, the optical controller **212** can obtain the optical power targets **242** for each in-service channel including the channels that were in-service prior to receiving the instruction to place in-service the additional channel, and including the newly in-service channel. In some examples, the SDN computing module **214** can provide the optical power targets **242** to the ROADM **202**, the optical controller **212**, or both. The SDN computing module **214** can provide the optical power targets **242** at the "start of life" of the ROADM **202**. In some examples, the optical power targets **242** are provided/specified by a governing body or consortium (e.g., the OpenROADM consortium). In some examples, the optical power targets **242** can differ for each in-service channel.

In some examples, the optical controller **212** obtains the optical power targets **242** by identifying the database **240** that can be stored by a local memory to the ROADM **202**. The database **240** can include the optical power targets **242** for each in-service channel of the ROADM **202**. The optical controller **212** can then access, from the database **240**, the optical power targets **242** for each in-service channel of the passthrough connection **234***a* and the optical connections **234***b*, **234***c*, . . . , **234***n* including the channels that were in-service prior to receiving the instruction to place in-service the additional channel, and including the newly in-service channel. In some examples, the optical controller **212** obtains the optical power targets **242** by receiving, for each of the in-service channels, the optical power targets **242** over the DCN **216** from the SDN computing module **214**.

The optical controller **212**, further in response to identifying an additional channel is to be in-service at the ROADM **202**, can equalize a transmit power for each in-service channel of the ROADM **202**. Specifically, the optical controller **212** can identify the transmit power of each in-service channel of the passthrough connection **234***a* or optical connections **234***b*, **234***c*, . . . , **234***n*. For example, the optical controller **212**, for each in-service channel including the channels that were in-service prior to receiving the instructions to place in-service the additional channel, and including the newly in-service channel, identifies the transmit power of the in-service channel. In some examples, the transmit power of the in-service channel can include the transmit power of the channel (and corresponding wavelength of the channel) that is output by the multiplexer **204***a*, i.e., the transmit power at the signals **236***a*. In some examples, the OCM **210** can identify the transmit power of the in-service channels (and corresponding wavelengths) that are output by the optical amplifier **208***c* (e.g., at the signals **237***a*) and transmit such data to the optical controller **212**. In other words, the OCM **210** can take per-channel power readings of all pre-existing in-service channels and the newly in-service channel.

The SDN computing module **214** can further provide instructions to transition the additional channel to be placed in-service to a power mode. In response, the optical controller **212**, in furtherance of equalizing the transmit power for each in-service channel of the ROADM **202**, can transition each in-service channel of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n* to a power mode. That is, the optical controller **212** can change the state of each of the in-service channels, including the channels that were in-service prior to receiving the instructions to place in-service the additional channel, and including the newly in-service channel, to a power mode to hold a constant optical power of the in-service channels. Specifically, the power mode of the channels can be employed by the optical controller **212** to place in-service additional channels, and/or place channels out of service, to achieve desired optical power targets, described further herein. The optical controller **212** transitions each of the channels that were in-service prior to receiving the instructions to place in-service the additional channel only in response to the instructions to transition the additional channel to be placed in-service to a power mode. That is, the SDN computing module **214** does not provide specific instructions to transition the remaining in-service channels to power mode other than the instructions to transition the additional channel to be in-service to a power mode.

The optical controller **212**, in furtherance of equalizing the transmit power for each in-service channel of the passthrough connection **234***a* and/or optical connection **234***b*, **234***c*, . . . , **234***n* of the ROADM **202**, can adjust the transmit power of each of the in-service channels. Specifically, the optical controller **212** can adjust the transmit power of each of the in-service channels, including the channels that were in-service prior to receiving the instructions to place in-service the additional channel, and including the newly in-service channel. In some examples, the optical controller **212** can adjust the transmit power of each of the in-service channels after transitioning each of the in-service channels to the power mode. The optical controller **212** can adjust the transmit power of each of the in-service channels based on, for each in-service channel, i) the optical power target **242** for the in-service channel and ii) the identified transmit power for the in-service channel.

Specifically, in some examples, the optical controller **212** can compare, for each in-service channel of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n*, the optical power target **242** for the in-service channel with the transmit power for the in-service channel. Based on such comparison, the optical controller **212** can adjust the transmit power of the in-service channel to more closely match the optical power target **242** (or within a threshold). In some examples, the optical controller **212** can adjust the transmit power of the in-service channel a predetermined amount, or any amount, to more closely match the optical power target **242** for the in-service channel. For example, the optical controller **212** can adjust a first in-service channel by increasing the transmit power of the first in-service channel, and adjust a second in-service channel by decreasing the transmit power of the second channel. In some examples, the transmit power of the second in-service channel is greater than the transmit power of the first in-service channel.

In some examples, the optical controller **212** can adjust the transmit power of the in-service channels of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n*, including the channels that were in-service prior to receiving the instructions to place in-service the additional channel. That is, the SDN computing module **214** can provide an instruction to adjust the transmit power of the newly in-service channel, and the optical controller **212** can adjust the remaining in-service channels independent of the instruction from the SDN computing module **214**.

FIG. **3** illustrates an example graph **300** displaying a nominal per channel power provisioning range for the in-service channels. Specifically, the graph **300** includes a first line **302** and a second line **304** of the exit span loss (dB) versus the per channel output power (dBm) defining the power provisioning range **306**. The first line **302** is an optimum transmit power for each in-service channel, and the second line **304** is a tolerance transmit power for each in-service channel. Specifically, the optical controller **212** can adjust the transmit power of each of the in-service channels to be within the power provisioning range **306**.

In some examples, after equalizing the transmit power for each of the in-service channels of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n* in the ROADM **202** at a first time, the optical controller **212** can equalize (or re-equalize), at a second time after the first time, the transmit power for each of the in-service channels. That is, the optical controller **212** can identify the updated transmit power of each in-service channel (after equalization of the transmit powers of the in-service channels at the first time). In some examples, the updated transmit power of the in-service channel can include the updated transmit power of the channel (and corresponding wavelength of the channel) that is output by the multiplexer **204***a*, i.e., the transmit power at the signals **236***a*. In some examples, the OCM **210** can identify the updated transmit power of the in-service channels (and corresponding wavelengths) that are output by the optical amplifier **208***c* (e.g., at the signals **237***a*) and transmit such data to the optical controller **212**.

The optical controller **212**, can compare, for each in-service channel of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n*, the optical power target **242** for the in-service channel with the updated transmit power for the in-service channel. Based on such comparison, the optical controller **212** can further adjust the updated transmit power of the in-service channel to more closely match the optical power target **242** (or within a threshold). In some examples, the optical controller **212** can adjust the updated transmit power of the in-service channel a predetermined amount, or any amount, to more closely match the optical power target **242** for the in-service channel.

To that end, the optical controller **212** can adjust the updated transmit power of each of the in-service channels of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n*. Specifically, the optical controller **212** can adjust the updated transmit power of each of the in-service channels, including the channels that were in-service prior to receiving the instructions to place in-service the additional channel, and the newly in-service channel. The optical controller **212** can adjust the updated transmit power of each of the in-service channels based on, for each in-service channel, i) the optical power target **242** for the in-service channel and ii) the identified updated transmit power for the in-service channel. Thus, the OCM **210** determines the transmit power of each of the in-service channels, and the optical controller **212** adjusts the same based on the optical power target **242** to form a feedback loop.

In some examples, the optical controller **212** can adjust, and re-adjust, the transmit power of each of the previously in-service channels of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n* a threshold number of times. For example, the optical controller **212** can adjust the transmit power of each of the previously in-service channels for two or three iterations. In some examples, the optical controller **212** can adjust the transmit power of each of the previously in-service channels until each of the in-service channels is within a tolerance of the respective optical power target **242**.

The SDN computing module **214** can further provide instructions to transition the additional channel to be placed in-service to a steady state mode. In response, the optical controller **212**, in furtherance of equalizing the transmit power for each in-service channel of the passthrough connections **234** of the ROADM **202**, transitions, at the ROADM **202**, the newly in-service channel to the steady state mode (e.g., a “gainLoss” mode). Furthermore, independent of instruction from the SDN computing module **214**, the optical controller **212**, in furtherance of equalizing the transmit power for each in-service channel, can transition each in-service channel that was in-service prior to receiving the instructions to place in-service the additional channel to the steady state mode (e.g., a “gainLoss” mode”). In some examples, the optical controller **212** can transition each of the in-service channels to the steady state mode after adjusting the transmit power of each of the in-service channels. The steady state mode of the in-service channels can include a static state of the in-service channels. In some examples, the optical controller **212** can transition each of the in-service channels to the steady state mode at any time.

In some examples, the optical controller **212** can transition each of the in-service channels independent of instructions from the SDN computing module **214** to transition each of the in-service channels. Specifically, the SDN computing module **214** may be unaware that the transmit power of each of the previously in-service channels are being adjusted.

In some implementations, the SDN computing module **214** can identify a previously in-service channel of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n* is to be placed out of service at the ROADM **202** (e.g., as put out of service by the SDN computing module **214**). Specifically, by placing the particular channel out of service, the channel’s power on the signals **236***a* is reduced significantly. That is, the particular channel is to be removed by the multiplexer **204***a*. In some examples, the SDN computing module **214** provides instructions to the ROADM **202** over the DCN **216** to place out of service the particular channel.

The optical controller **212**, in response to identifying the particular channel is to be placed out of service at the ROADM **202**, can obtain the optical power targets **242** (or data indicating the optical power targets **242**) for each in-service channel. For example, the optical controller **212** can obtain the optical power targets **242** for each in-service channel.

The optical controller **212**, further in response to identifying the particular channel of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n* is to be placed out of service at the ROADM **202**, can equalize a transmit power for each in-service channel of the ROADM **202**, and the transmit power of the channel to be placed out of service (to a low power target). Specifically, the optical controller **212** can identify the transmit power of each in-service channel. In some examples, the transmit power of the in-service channel can include the transmit power of the channel (and corresponding wavelength of the channel) that is output by the multiplexer **204***a*, i.e., the transmit power at the signals **236***a*. In some examples, the OCM **210** can identify the transmit power of the in-service channels (and corresponding wavelengths) that are output by the optical amplifier **208***c* (e.g., at the signals **237***a*) and transmit such data to the optical controller **212**. In other words, the OCM **210** can take per-channel power readings of all pre-existing in-service channels and the channel to be placed out of service.

The SDN computing module **214** can further provide instructions to transition the channel to be placed out of service to a power mode. In response, the optical controller **212**, in furtherance of equalizing the transmit power for each in-service channel of the ROADM **202**, can transition each in-service channel and the channel to be placed out of service to a power mode. That is, the optical controller **212** can change the state of each of the in-service channel to a power mode to hold a constant optical power of the in-service channels. The optical controller **212** transitions each of the remaining channels that were in-service prior to receiving the instructions to place the particular channel out of service only in response to the instructions to transition the particular channel to be placed out of service to a power mode. That is, the SDN computing module **214** does not provide specific instructions to transition the remaining in-service channels to power mode other than the instructions to transition the particular channel to be placed out of service to a power mode.

The optical controller **212**, in furtherance of equalizing the transmit power for each in-service channel of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***c*, . . . , **234***n* of the ROADM **202**, can adjust the transmit power of each of the in-service channels and the channel to be placed out of service. In some examples, the optical controller **212** can adjust the transmit power of each of the in-service channels and the channel to be placed out of service after transitioning each of the in-service channels and the channel to be placed out of service to the power mode. The optical controller **212** can adjust the transmit power of each of the in-service channels and the channel to be placed out of service based on, for each in-service channel and the channel to be placed out of service, i) the optical power target **242** for the in-service channel and the channel to be placed out of service and ii) the identified transmit power for the in-service channel and the channel to be placed out of service.

The SDN computing module **214** can further provide instructions to transition the channel to be placed out of service to a power mode. In response, the optical controller **212**, in furtherance of equalizing the transmit power for each in-service channel of the ROADM **202**, transitions, at the ROADM **202**, each in-service channel to a steady state mode. In some examples, the optical controller **212** can transition each of the in-service channels to the steady state mode after adjusting the transmit power of each of the in-service channels. The steady state mode of the in-service channels can include a static state of the in-service channels. In some examples, the optical controller **212** can transition each of the in-service channels to the steady state mode at any time.

In some implementations, a new channel of the passthrough connection **238***a* and/or the optical connections **238***b*, **238***c*, . . . , **238***n* can be placed in-service, or a previously placed in-service channel of the passthrough connection **238***a* and/or the optical connections **238***b*, **238***c*, . . . , **238***n* can be placed out of service, similar to that described herein with respect to channels of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***b*, **234***n*. In some examples, the new channel of the passthrough connection **238***a* and/or the optical connections **238***b*, **238***c*, . . . , **238***n* can be placed in-service, or the previously placed in-service channel of the passthrough connection **238***a* and/or the optical connections **238***b*, **238***c*, . . . , **238***n* can be placed out of service, in combination with placing in-service a new channel of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***b*, **234***n* or placing out of service a previously placed in-service channel of the passthrough connection **234***a* and/or the optical connections **234***b*, **234***b*, **234***n*.

In some examples, the SDN computing module **214** can further provide instructions to transition the channel to be placed out of service to an off mode. In response, the optical controller **212** can transition the channel to be placed out of service to an off mode. That is, the optical controller **212** can adjust the transmit power of the channel to be placed out of service (and corresponding wavelength of the channel) to have a maximum loss that is created by the respective multiplexers **204***a*, **204***b* and demultiplexers **206***a*, **206***b*.

In some examples, the optical environment **200** can include multiple ROADMs **202**. For example, once the optical controller **212** adjusts the transmit powers of the in-service channels of the passthrough connections **234***a*, **238***a* and/or the optical connections **234**, **238** based on the optical power targets **242**, a further optical controller **212** of a further ROADM can similarly adjust the transmit powers of respective in-service channels based on respective power targets **242**.

For example, referring to FIG. **4**, the optical environment can include a point-to-point optical network **400**; referring to FIG. **5**, the optical environment can include a linear optical network **500**; and referring to FIG. **6**, the optical environment can include a ring optical network **600**.

Specifically, when the optical network includes the ring optical network **600**, the ROADM **202**, and in particular, the optical controller **212**, can help facilitate obtaining a stability of the ring optical network **600**. Specifically, when the net loop gain is more than zero dB, as the optical signals transmit through the ring optical network **600**, the power of the optical signals increase, thus forming an unstable ring—e.g., optical lasing of the ring optical network **600**. To that end, by adjusting the transmit power of the in-service channels at each ROADM of an optical network—e.g., the ring optical network **600**—the loop gain of the ring optical network **600** is minimized, if not prevented, such that lasing of the ring optical network **600** is prevented.

FIGS. **7**A, **7**B illustrate an optical environment **700** including optical blades **702***a*, **702***b*, **702***c*, **702***d* (collectively referred to as optical blades **702**). The blades **702***b*, **702***d*, for example, could constitute an optical "passthrough" node. The optical blades **702** can include the ROADM **202** of FIG. **2**. To that end, in an example, during channel turn-up at the optical blade **702***a*, a SDN computing module can provide instructions to the optical blade **702***a* to add a newly in-service channel at a specified target power. When the newly in-service channel is added within a time period, the SDN computing module can instruct the blade **702***a* to change state to the steady state mode ("gainLoss" mode). However, if the blade **702***a* is unable to achieve the specified target power of the newly in-service channel within the specified target power, the SDN computing module can instruct the blade **702***a* to change state to an off mode. The SDN computing module repeats the same sequentially node by node downstream to the drop node (e.g., the blade **702***c*). The SDN computing module can hold the drop node (e.g., the blade **702***c*) in a constant power state. In some examples, for new channel turn up, power adjustment starts at a first multiplexer connected to the add transponder, and then proceeds in sequence downstream through all nodes in serial (only after the previous upstream device has been placed in a steady state by the SDN computing module) to the eventual far end drop node. The far end drop node remains in power, and does not transition to a steady state. In some examples, only one multiplexer (e.g., multiplexer **204***a*, **204***b*) or demultiplexer (e.g., demultiplexer **206***a*, **206***b*) adjusts at a time (e.g., in the proper sequence) in a node or in the network. In some examples, two or more multiplexers or demultiplexers can adjust at a same time in a node or in the network. In some examples, each of the multiplexers and demultiplexers can adjust at a same time in a node or in the network.

Furthermore, in an example, during channel turn-down, an in-service channel is turned down sequentially in reverse order starting at the drop node (e.g., the blade **702***c*). The SDN computing module can instruct the blade **702***c* to set the mode of the channel to off after ramping down the power of the channel. In some examples, for placing a channel out of service, power adjustment starts at a first demultiplexer connected to the drop transponder, and then proceeds in sequence upstream through all nodes in serial (only after the previous downstream device has been placed in an off state by the SDN computing module) to the eventual add node. In some examples, only one multiplexer (e.g., multiplexer **204***a*, **204***b*) or demultiplexer (e.g., demultiplexer **206***a*, **206***b*) adjusts at a time (e.g., in the proper sequence) in a node or in the network. In some examples, two or more multiplexers or demultiplexers can adjust at a same time in a node or in the network. In some examples, each of the multiplexers and demultiplexers can adjust at a same time in a node or in the network.

In some examples, the optical environment **700** can be in steady state operation—all blades **702** are in a steady state mode ("gainLoss" mode) except the drop blade **702***c* that is in a power mode. In some examples, the optical environment **700** can be in a steady state operation with an upstream fiber cut/restore. That is, all blades **702** are in the steady state mode except drop blade **702***c* that is in power mode when the in-service channel is lost. Specifically, the blade **702***c* detects a channel loss of service and freezes the corresponding demultiplexer for any channels that are dropped, and maintain power for channels that were not dropped. If/when the loss of service clears, the blade **702***c* can resume a previous mode (e.g., power mode).

In some examples, the optical environment **700** can be in be a channel turn-up operation—the SDN computing module can equalize the power of a channel starting at the add node and then working downstream and then set the channel in steady state mode and the drop blade **702***c* in power mode. Specifically, the SDN computing module can provide instructions to the blade **702***a* to equalize the transmit power of the newly turned-up channel. In reaction, an optical controller sets all in service channels to power mode. The SDN will transition the state of the newly turned-up channel to steady state but the optical controller may autonomously do the same for the pre-existing in-service channels. The SDN computing module can provide instructions to the drop blade **702***c* to equalize the power of the in-service channels.

In some examples, the optical environment **700** can turn-up a channel at the add blade **702***a* with a fiber cut/restore. Specifically, the blade **702***a* detects a channel loss of signal and dropped channels freeze equalization in mux. Once the loss of channel clears, the previous power mode is resumed. After equalization is completed, the channels transition to a steady state mode.

In some examples, the optical environment **700** can turn-up a channel at the through node containing **702***b* and **702***d*, with upstream fiber cut/restore. Specifically, the node containing **702***b* and **702***d* maintains power for any channels not dropped but dropped channels freeze equalization in mux and demux. If/when the loss of service clears, the node containing **702***b* and **702***d* can resume a previous mode (e.g., power mode); and after equalization completes, the channels can transition to a steady state mode.

In some examples, the optical environment **700** can turn-up a channel at the through node containing **702***b* and **702***d*, with a passthrough fiber cut/restore. Specifically, the through node containing **702***b* and **702***d* is in channel turn up, with channel input lost at an egress blade of the node containing **702***b* and **702***d*. The node containing **702***b* and **702***d* maintains power for any channels not dropped but dropped channels freeze equalization in mux. If/when the loss of service clears, the node containing **702***b* and **702***d* can resume a previous mode (e.g., power mode); and after equalization completes, the channels can transition to a steady state mode.

In some examples, the optical environment **700** can turn-up a channel at the drop blade **702***c*, with an upstream fiber cut/restore. Specifically, the blade **702***c* maintains power for any channels not dropped but dropped channel freezes equalization in demux. If/when the loss of service clears, the blade **702***c* can resume a previous mode (e.g., power mode); and after equalization completes, the channels can transition to a steady state mode.

In some examples, the optical environment **700** can turn down a channel—blades **702***a*, **702***b*, **702***d* begin in a steady state operation and the node containing **702***c* is in a power mode. The SDN computing module provides instructions to the drop node containing blade **702***c* to turn down channel power, then off; and provides instructions to the passthrough node **702***b* and **702***d* to turn down channel power, then off. This is repeated sequentially in reverse order starting at the drop node containing **702***c* and working towards the add blade **702***a*. Furthermore, each of the in-service channels can be automatically set to power mode, and the remaining channels not being turned down can be automatically set to steady-state mode ("gainLoss" mode).

FIG. **8** illustrates a flowchart depicting selected elements of an embodiment of a method **800** for transmit power equalization. The method **800** may be performed by the optical environment **200** and/or the optical controller **212** described herein with reference to FIGS. **1-7**. It is noted that certain operations described in method **800** may be optional or may be rearranged in different embodiments.

The ROADM **202** is identified (**802**). The ROADM includes in-service channels. The optical controller **212** identifies an additional channel that is to be in-service at the ROADM **202** or an existing channel that is to be taken out of service (**804**). In response to identifying the additional channel is to be in-service or the existing channel that is to be taken out of service at the ROADM **202**, the optical controller **212** obtains optical power targets **242** for each in-service channel of the ROADM (**806**). Each in-service channel includes each previously in-service channel and the newly in-service channel. The optical controller **212** transitions, at the ROADM **202**, each in-service channel to a power mode (**808**). The optical controller **212**, after transitioning each in-service channel to the power mode, adjusts, at the ROADM **202**, the transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified transmit power for each in-service channel (**810**). The optical controller **212**, after adjusting the transmit power of each in-service channel and in response to instructions from the SDN computing module **214**, transitions, at the ROADM **202**, each in-service channel to a steady state mode (**812**). Furthermore, independent of instructions from the SDN computing module **214**, the optical controller may transition each previously in-service channel to the steady state mode. The optical controller **212** can, if an in-service channel is to be placed out of service, can transition the channel to an off mode (**814**).

The above disclosed subject matter is to be considered illustrative, and not restrictive, and the appended claims are intended to cover all such modifications, enhancements, and other embodiments which fall within the true spirit and scope of the present disclosure. Thus, to the maximum extent allowed by law, the scope of the present disclosure is to be determined by the broadest permissible interpretation of the following claims and their equivalents, and shall not be restricted or limited by the foregoing detailed description.

Herein, "or" is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A or B" means "A, B, or both," unless expressly indicated otherwise or indicated otherwise by context. Moreover, "and" is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A and B" means "A and B, jointly or severally," unless expressly indicated otherwise or indicated otherwise by context.

The scope of this disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments described or illustrated herein that a person having ordinary skill in the art would comprehend. The scope of this disclosure is not limited to the example embodiments described or illustrated herein. Moreover, although this disclosure describes and illustrates respective embodiments herein as including particular components, elements, features, functions, operations, or steps, any of these embodiments may include any combination or permutation of any of the components, elements, features, functions, operations, or steps described or illustrated anywhere herein that a person having ordinary skill in the art would comprehend. Furthermore, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative.

What is claimed is:

1. A computer-implemented method, comprising:

identifying a reconfigurable optical add-drop multiplexer (ROADM), the ROADM including a plurality of previously in-service channels;

identifying, by an optical controller, an additional channel that is to be placed in-service at the ROADM;

in response to identifying that the additional channel is to be placed in-service at the ROADM:

obtaining, by the optical controller, optical power targets for each in-service channel including the plurality of previously in-service channels and the additional in-service channel;

equalizing, by the optical controller, a transmit power for each in-service channel of the ROADM, including:

identifying the transmit power of each in-service channel;

transitioning, at the ROADM, each in-service channel to a power mode;

after transitioning each in-service channel to the power mode, adjusting, at the ROADM, the transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified transmit power for the in-service channel; and

after adjusting the transmit power of each in-service channel, transitioning, at the ROADM, each previously in-service channel to a steady state mode independent of instruction from a software-defined networking (SDN) computing module.

2. The computer-implemented method of claim **1**, further comprising:

after equalizing the transmit power for each in-service channel of the ROADM, at a first time, equalizing, by the optical controller and at a second time after the first time, the transmit power for each in-service channel, including:

identifying an updated transmit power of each in-service channel; and

adjusting, at the ROADM, the updated transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified updated transmit power for the in-service channel.

3. The computer-implemented method of claim **1**, wherein adjusting the transmit power of each in-service channel further comprises:

adjusting a first in-service channel by increasing the transmit power of the first in-service channel; and

adjusting a second in-service channel by decreasing a transmit power of the second in-service channel.

4. The computer-implemented method of claim **1**, wherein obtaining the optical power targets includes:

receiving, for each in-service channel, the optical power targets over a network from the SDN computing module.

5. The computer-implemented method of claim 1, wherein the optical controller equalizes the transmit power for each previously in-service channel only in response to instructions from the SDN computing module to transition the additional channel to the power mode.

6. The computer-implemented method of claim 1, wherein the transmit power is equalized, for each previously in-service channel, less than or equal to a threshold number of times.

7. The computer-implemented method of claim 1, wherein in response to identifying that the additional channel is to be placed in-service, the transmit power of each in-service channel is adjusted initially at a first multiplexer connected to an add transponder and proceed in sequence downstream through each node serially including a far end drop node.

8. A computer-implemented method, comprising:
- identifying a reconfigurable optical add-drop multiplexer (ROADM), the ROADM including a plurality of previously in-service channels;
- identifying, by an optical controller, that a previously in-service channel is to be placed out of service at the ROADM;
- in response to identifying that the previously in-service channel is to be placed out of service at the ROADM:
  - obtaining, by the optical controller, optical power targets for each in-service channel;
  - equalizing, by the optical controller, a transmit power for each in-service channel of the ROADM, including:
    - identifying the transmit power of each in-service channel;
    - transitioning, at the ROADM, each in-service channel to a power mode;
    - after transitioning each in-service channel to the power mode, adjusting, at the ROADM, the transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified transmit power for the in-service channel; and
    - after adjusting the transmit power of each in-service channel, transitioning, at the ROADM, each remaining in-service channel to a steady state mode independent of instruction from a software-defined networking (SDN) computing module.

9. The computer-implemented method of claim 8, further comprising:
- after equalizing the transmit power for each in-service channel of the ROADM, at a first time, equalizing, by the optical controller and at a second time after the first time, the transmit power for each in-service channel, including:
  - identifying an updated transmit power of each in-service channel; and
  - adjusting, at the ROADM, the updated transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified updated transmit power for the in-service channel.

10. The computer-implemented method of claim 8, wherein adjusting the transmit power of each in-service channel further comprises:
- adjusting a first in-service channel by increasing the transmit power of the first in-service channel; and
- adjusting a second in-service channel by decreasing a transmit power of the second in-service channel.

11. The computer-implemented method of claim 8, wherein obtaining the optical power targets includes:
- receiving, for each in-service channel, the optical power targets over a network from the SDN computing module.

12. The computer-implemented method of claim 8, wherein the optical controller equalizes the transmit power for each in-service channel only in response to instructions from the SDN computing module to transition the previously in-service channel to be placed out of service to the power mode.

13. The computer-implemented method of claim 8, wherein the transmit power is equalized, for each previously in-service channel, less than or equal to a threshold number of times.

14. The computer-implemented method of claim 8, wherein in response to identifying that the previously in-service channel is to be placed out of service, the transmit power of each in-service channel is adjusted initially at a first demultiplexer connected to a drop transponder and proceed in sequence upstream through each node serially including an add node.

15. An optical system, comprising:
- a reconfigurable optical add-drop multiplexer (ROADM), the ROADM including a plurality of previously in-service channels;
- a software-defined networking (SDN) computing module in communication with the ROADM over a dynamic circuit network (DCN), the SDN computing module providing an instruction to place in-service an additional channel at the ROADM;
- an optical controller included by the ROADM and configured to, in response to the instruction to place in-service the additional channel at the ROADM:
  - obtain optical power targets for each in-service channel including the plurality of previously in-service channels and the additional in-service channel;
  - equalize a transmit power for each in-service channel of the ROADM, including:
    - identify the transmit power of each in-service channel;
    - transition, at the ROADM, each in-service channel to a power mode;
    - after transitioning each in-service channel to the power mode, adjust, at the ROADM, the transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified transmit power for the in-service channel; and
    - after adjusting the transmit power of each in-service channel, transition, at the ROADM, each previously in-service channel to a steady state mode independent of instruction from a software-defined networking (SDN) computing module.

16. The system of claim 15, wherein adjusting the transmit power of each in-service channel further comprises:
- adjusting a first in-service channel by increasing the transmit power of the first in-service channel; and
- adjusting a second in-service channel by decreasing a transmit power of the second in-service channel.

17. The system of claim 15, wherein obtaining the optical power targets includes:
- receiving, for each in-service channel, the optical power targets over a network from the SDN computing module.

18. The system of claim **15**, wherein the transmit power is equalized, for each previously in-service channel, less than or equal to a threshold number of times.

19. The system of claim **15**, wherein in response to identifying that the additional channel is to be placed in-service, the transmit power of each in-service channel is adjusted initially at a first multiplexer connected to an add transponder and proceed in sequence downstream through each node serially including a far end drop node.

20. The system of claim **15**, the optical controller further configured to:

after equalizing the transmit power for each in-service channel of the ROADM, at a first time, equalizing, by the optical controller and at a second time after the first time, the transmit power for each in-service channel, including:

identifying an updated transmit power of each in-service channel; and

adjusting, at the ROADM, the updated transmit power of each in-service channel based on, for each in-service channel, the optical power target for the in-service channel and the identified updated transmit power for the in-service channel.

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